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Milton et al.

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(54) **MOTOR GEARBOX ASSEMBLY**
(71) Applicant: **NIKOLA MOTOR COMPANY LLC**,
Salt Lake City, UT (US)
(72) Inventors: **Trevor R. Milton**, Salt Lake City, UT
(US); **Kevin M. Lynk**, Salt Lake City,
UT (US); **Anthony A. Heaton**,
Bountiful, UT (US); **Morgan**
Mackelprang, Salt Lake City, UT (US);
Steve Jennes, Fullerton, CA (US);
Adrian Hawkins, Hood River, OR
(US)
(73) Assignee: **NIKOLA MOTOR COMPANY LLC**,
Salt Lake City, UT (US)

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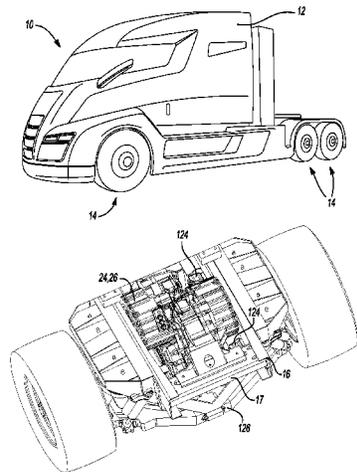
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Primary Examiner — Brian L Swenson
(74) *Attorney, Agent, or Firm* — Brooks Kushman P.C.

(57) **ABSTRACT**

A motor gearbox and suspension arrangement is provided
for a vehicle. The arrangement includes a drive system for
driving a wheel of the vehicle, and the drive system includes
an electric motor and a gear train associated with the motor.
The arrangement further includes a housing that receives the
motor and the gear train, and a suspension control arm
having a first end configured to be connected to the vehicle
and a second end configured to be connected to the housing.

15 Claims, 13 Drawing Sheets



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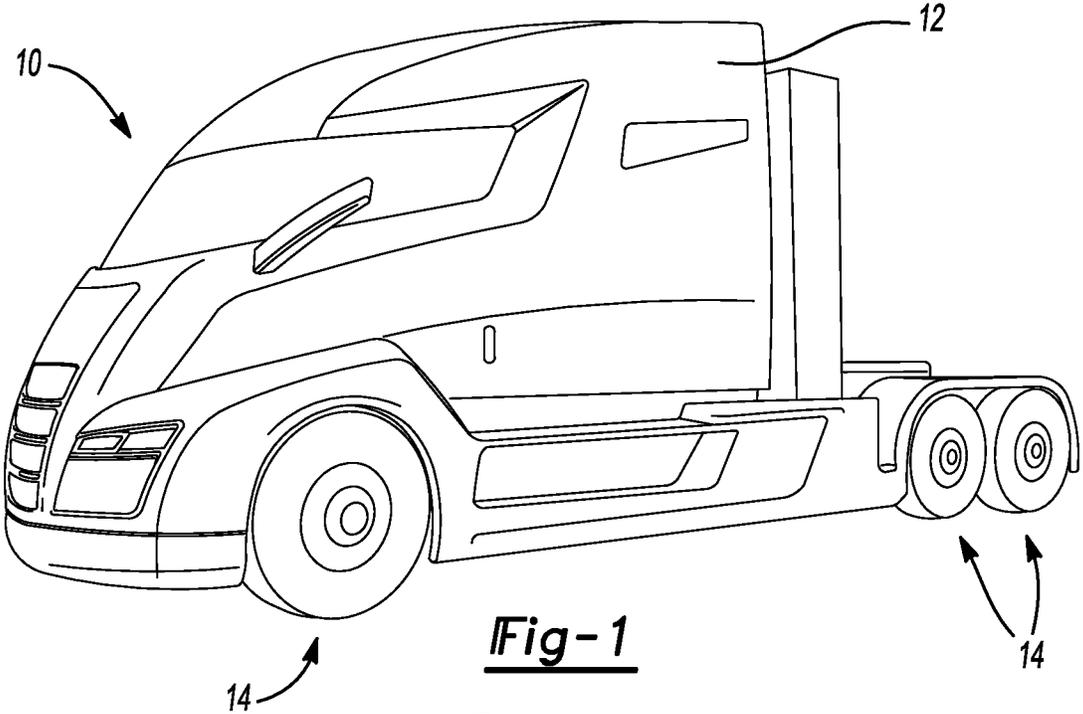


Fig-1

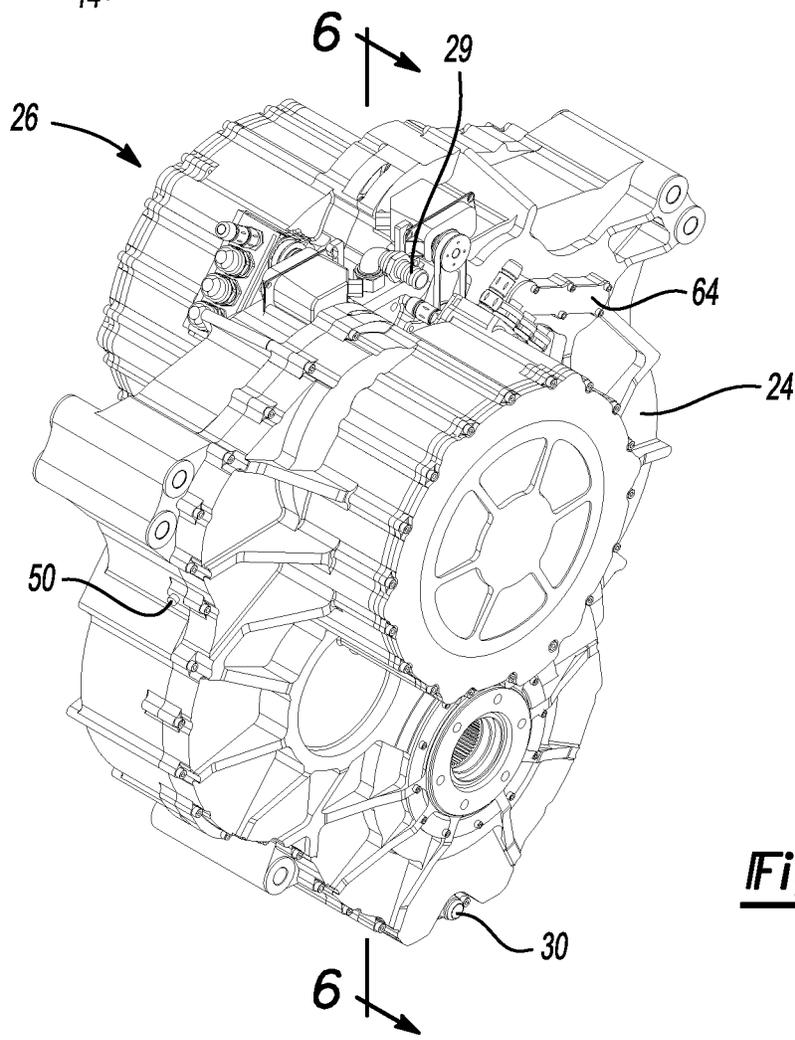


Fig-4

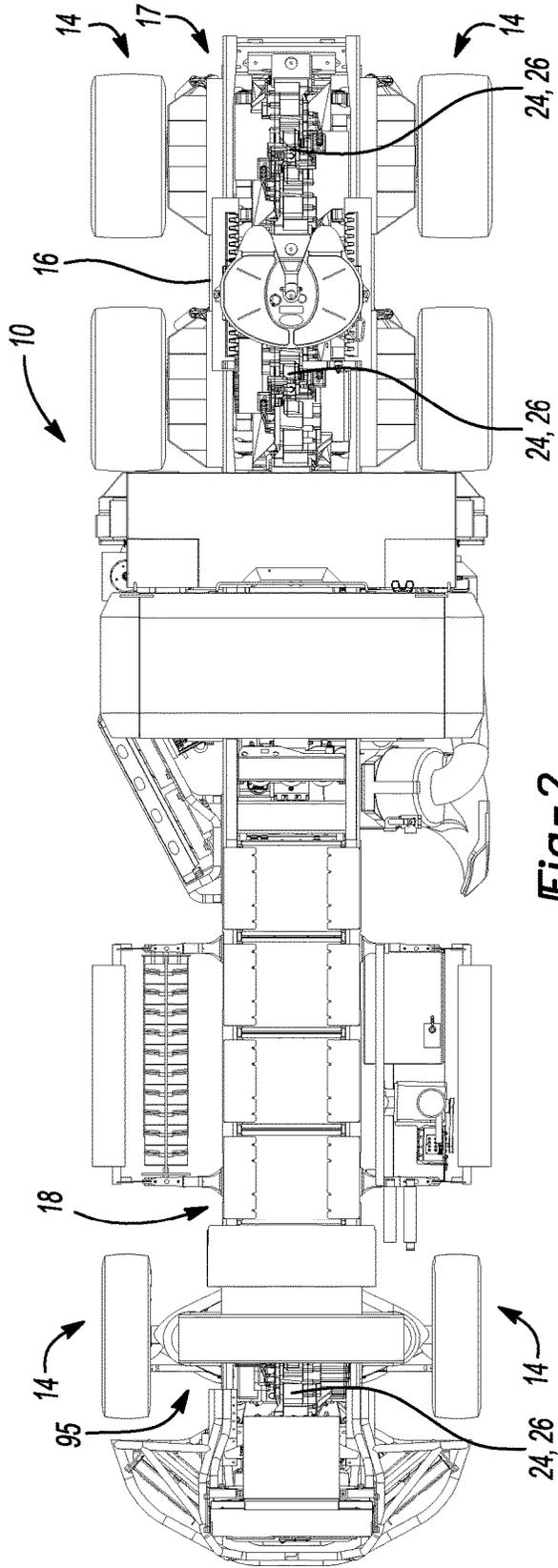


Fig-2

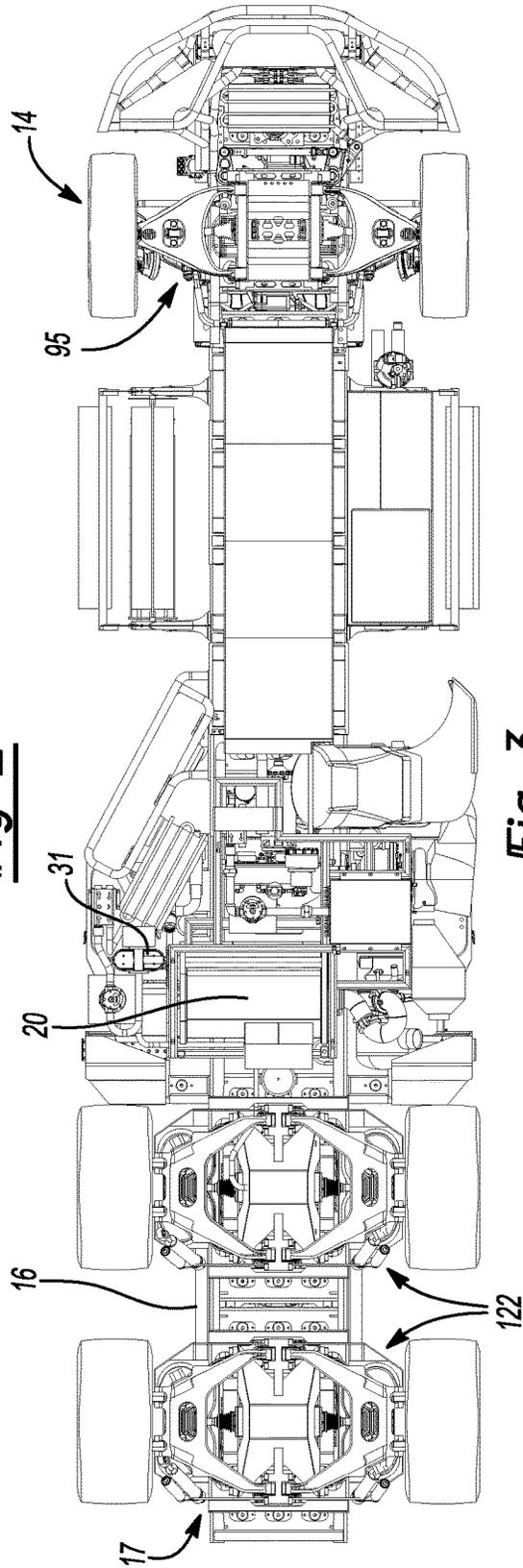


Fig-3

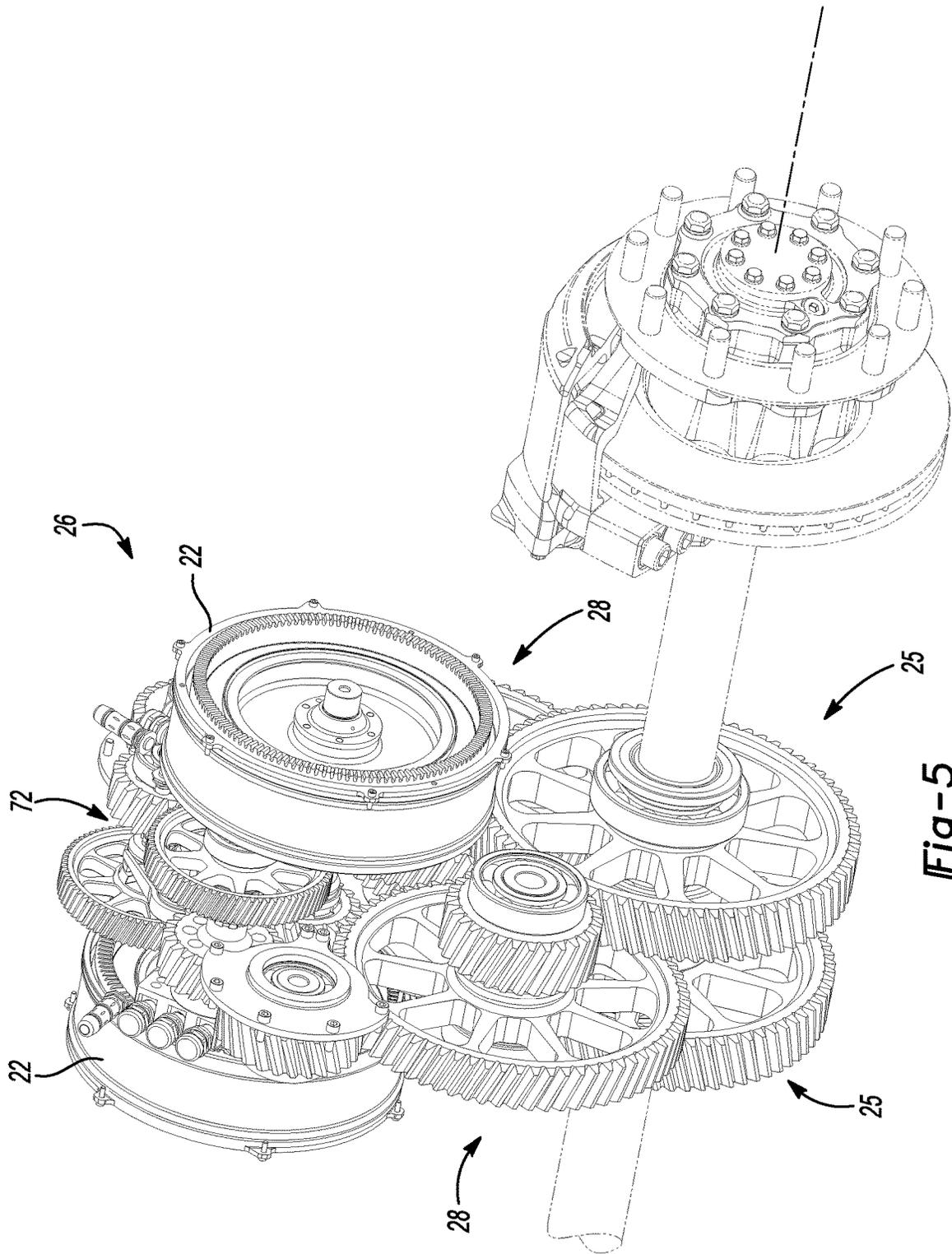


Fig-5

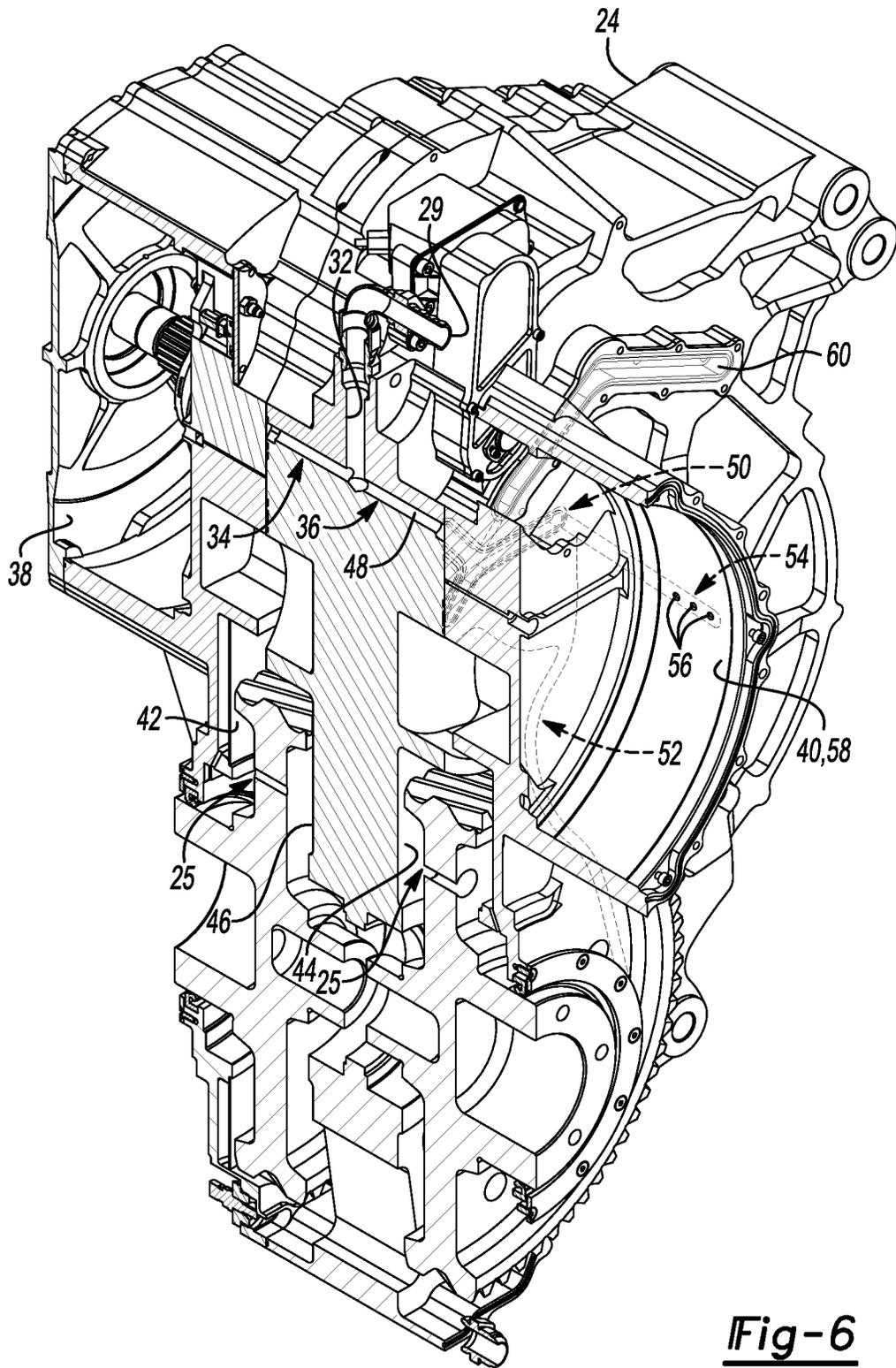


Fig-6

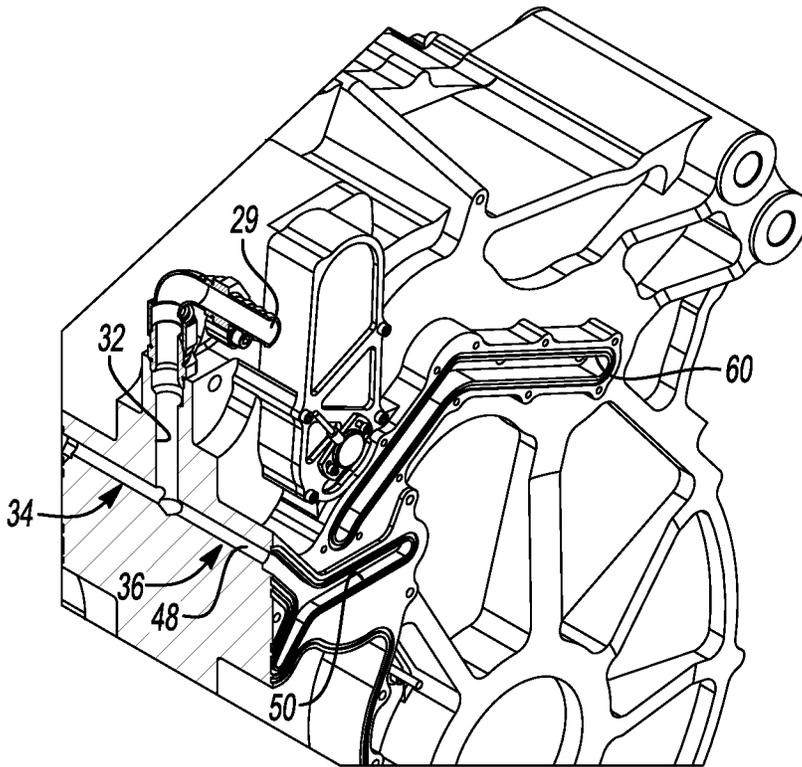


Fig-7

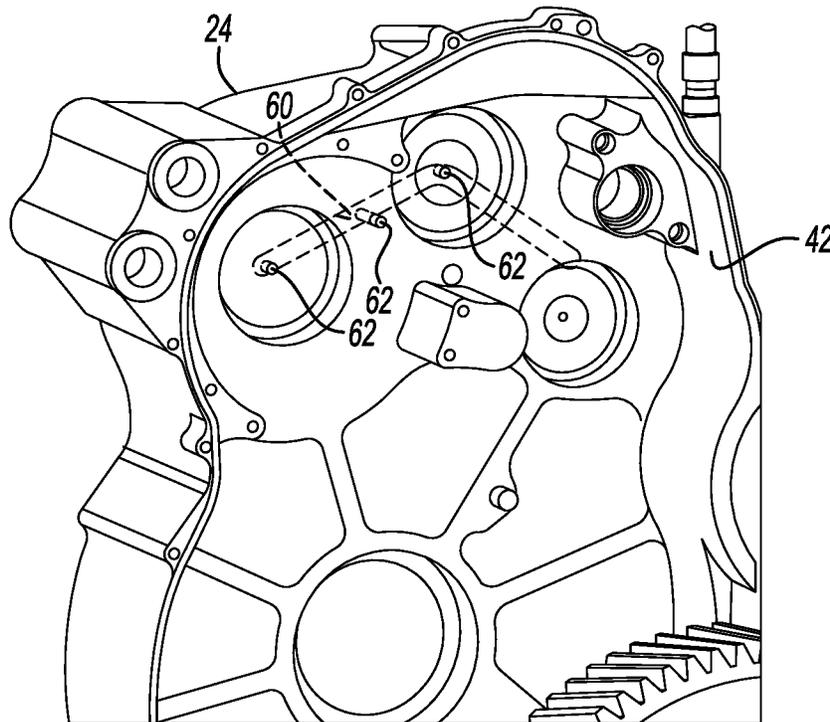


Fig-8

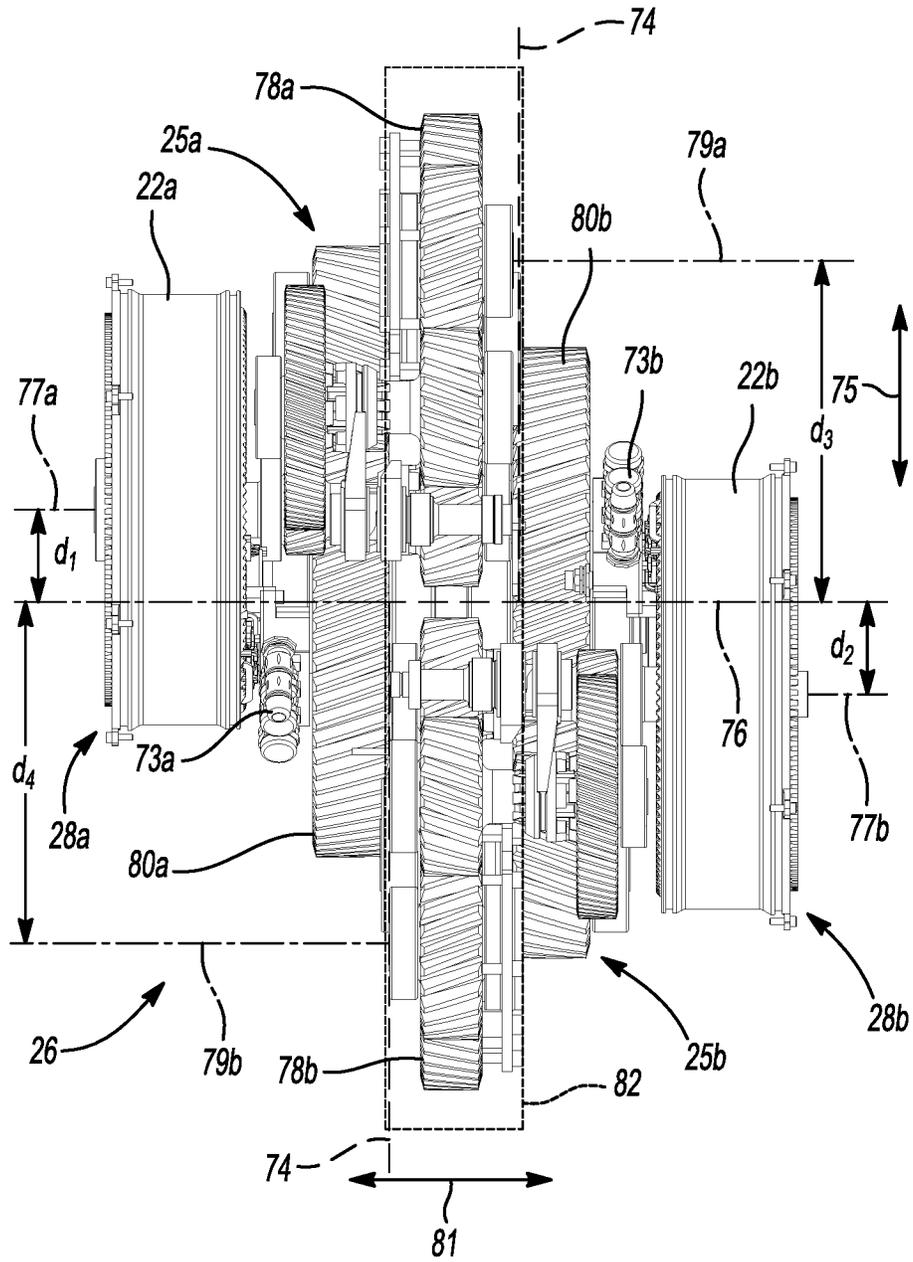


Fig-9

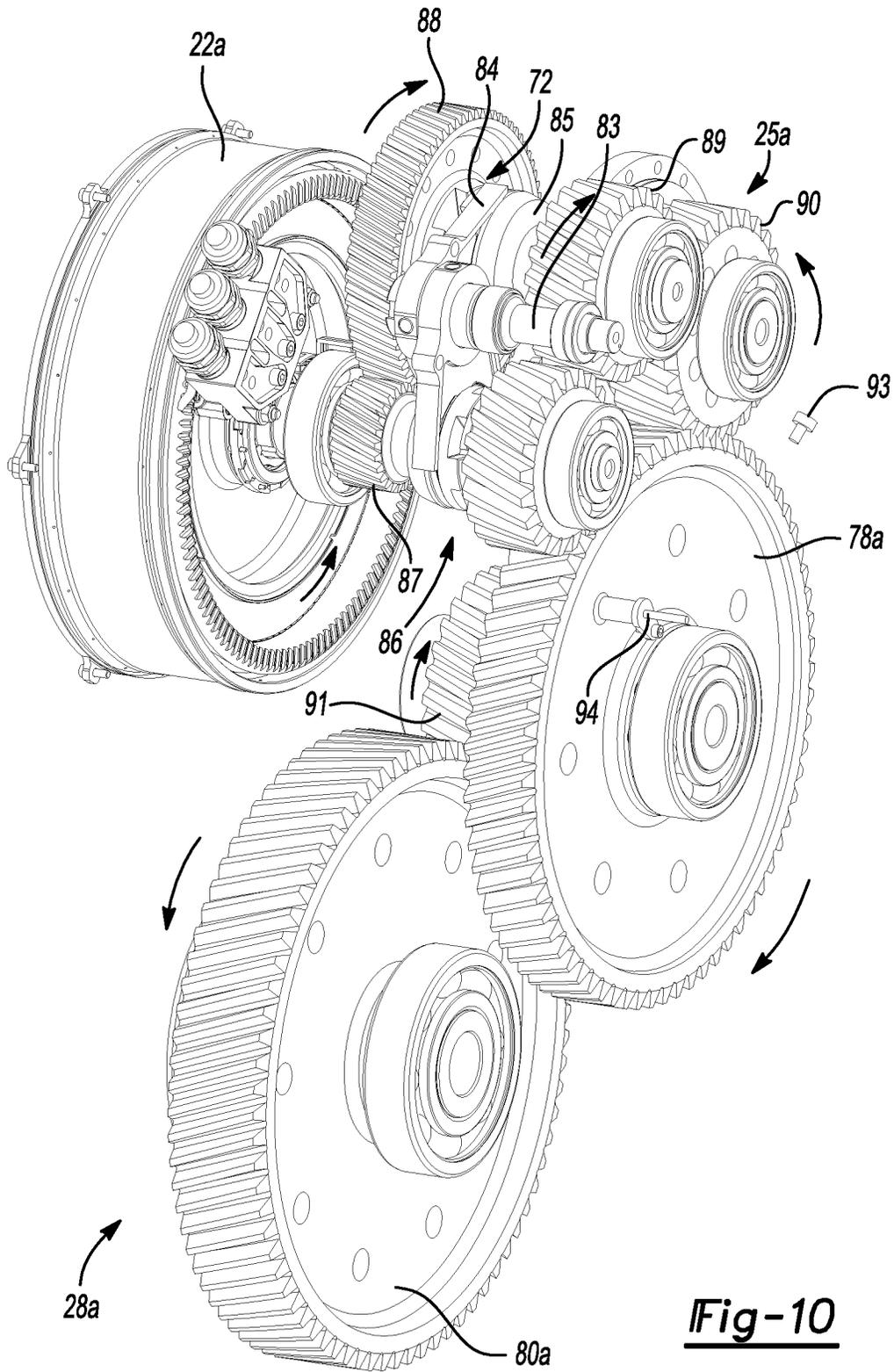


Fig-10

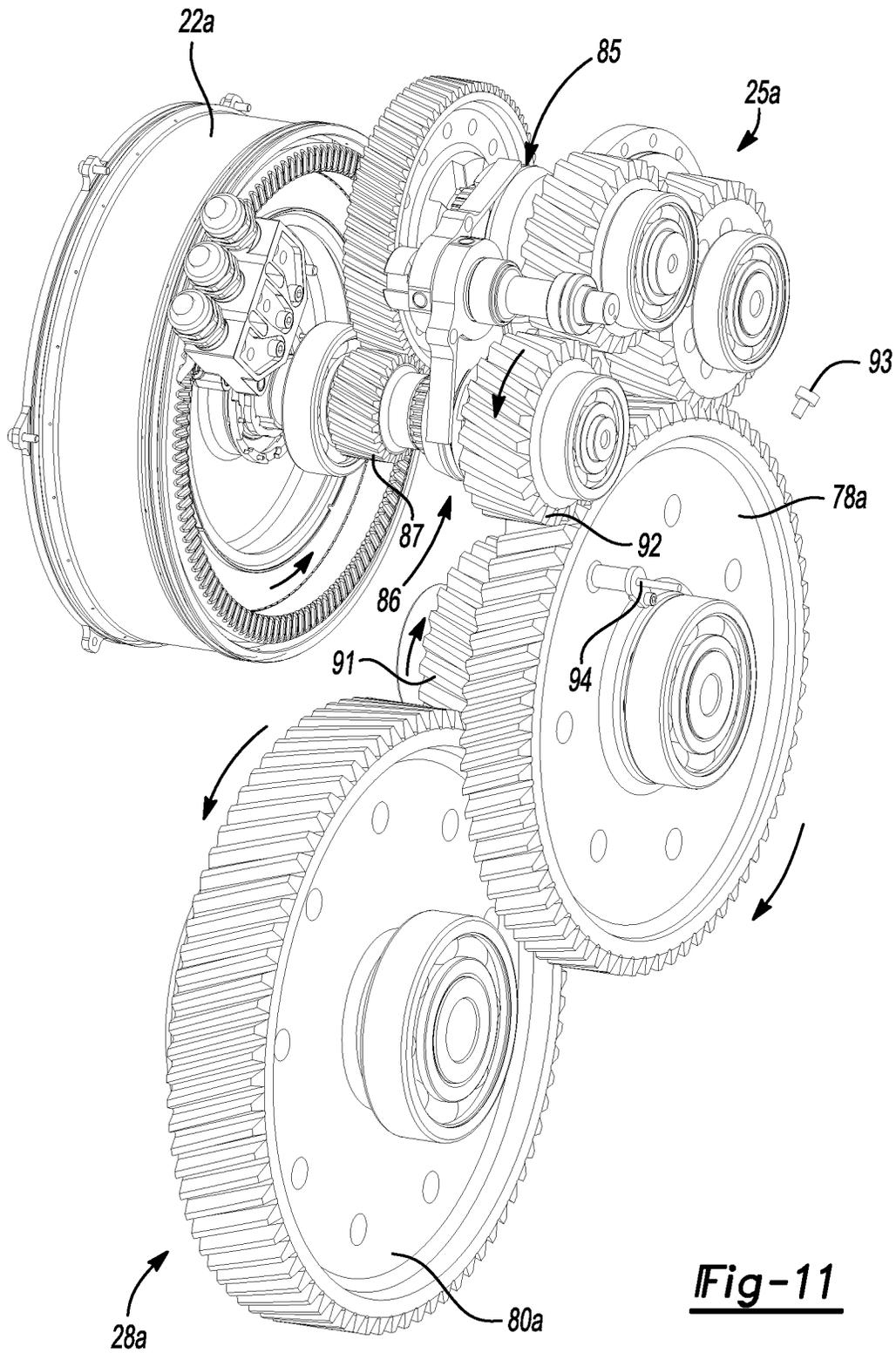


Fig-11

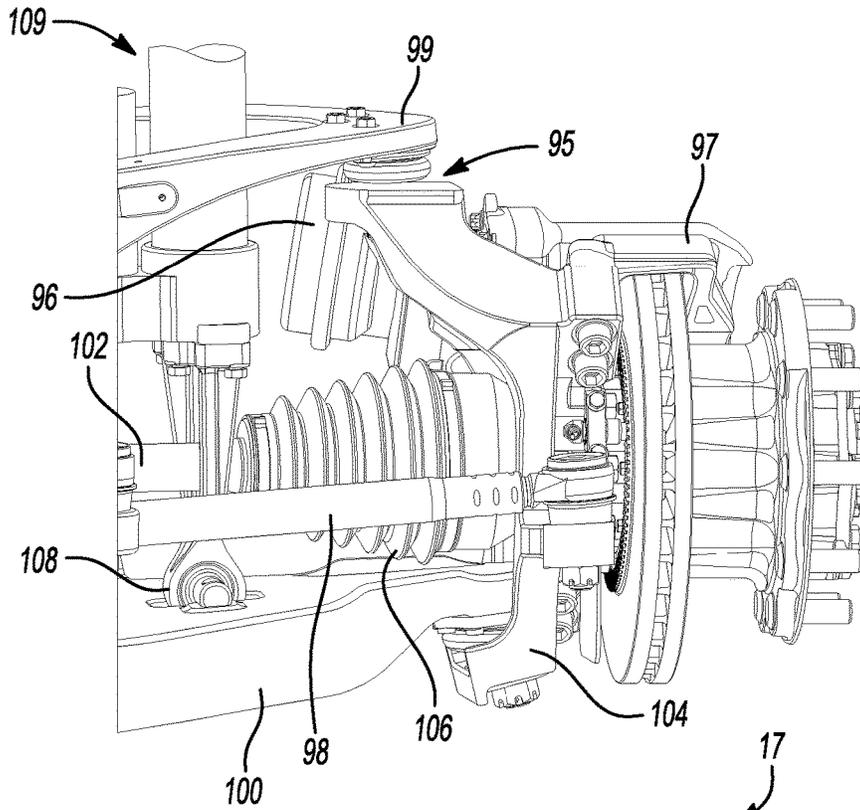


Fig-12

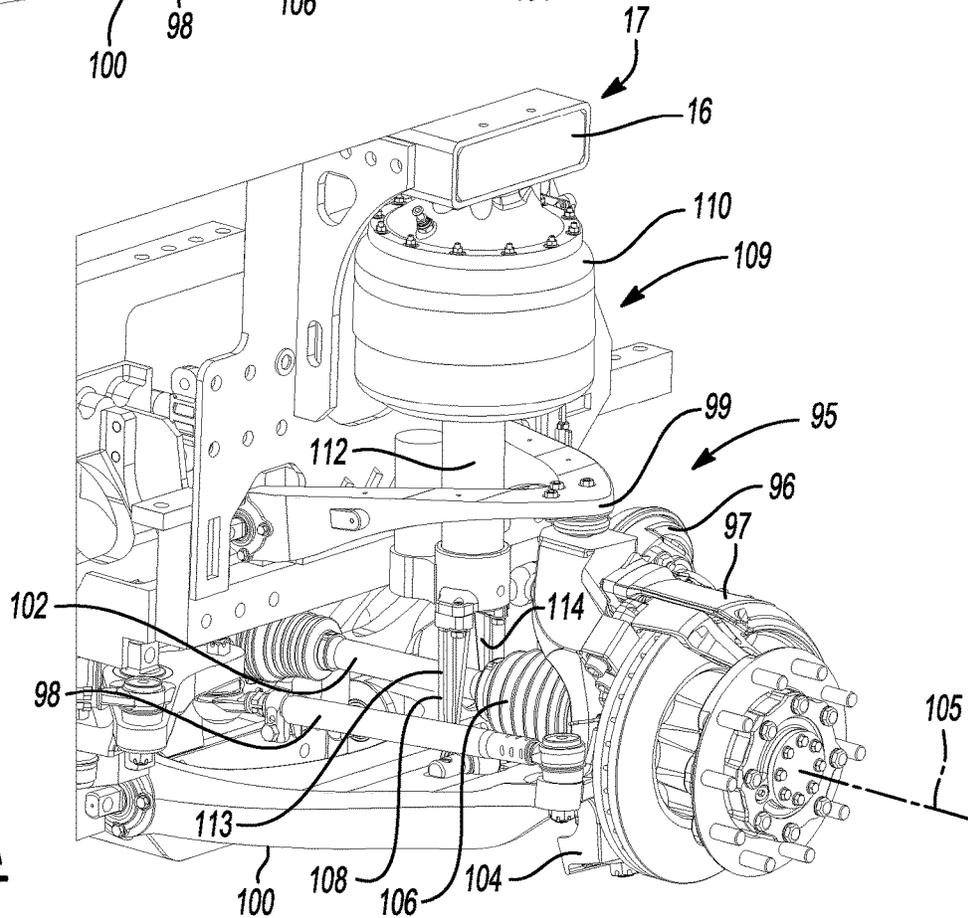


Fig-13A

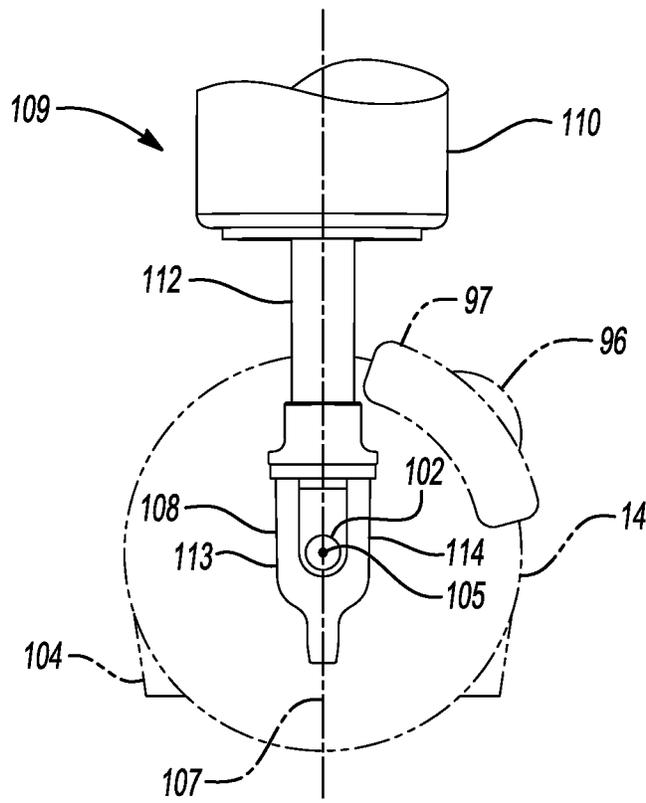


Fig-13B

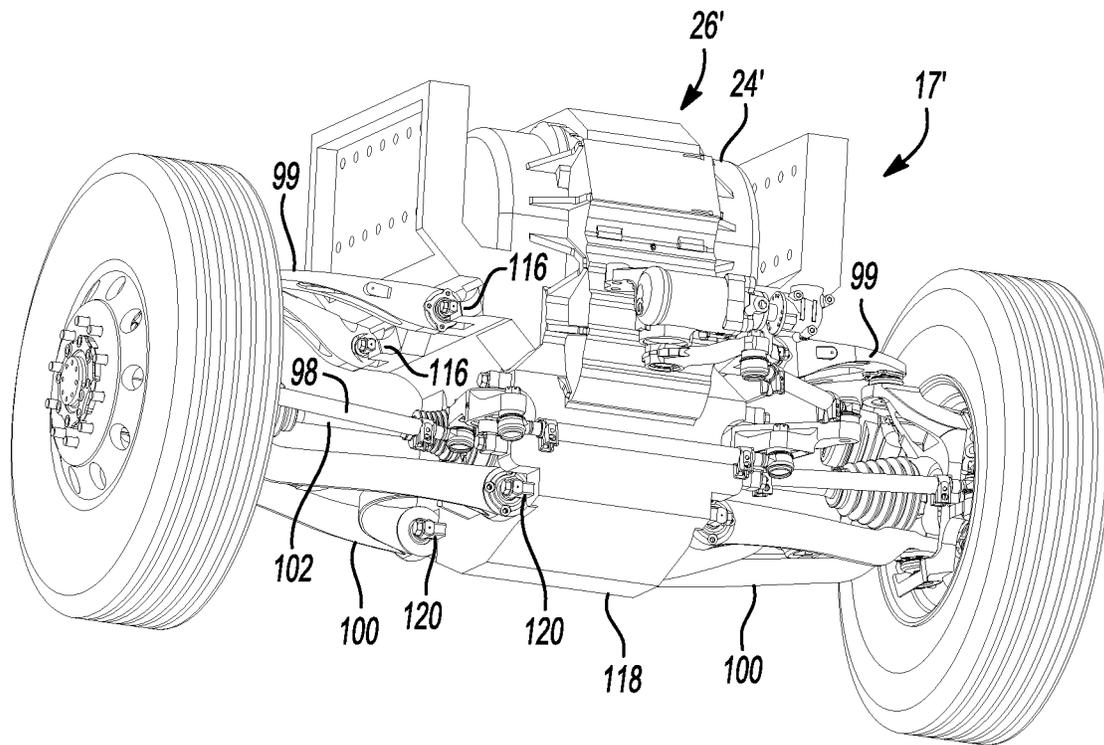


Fig-14

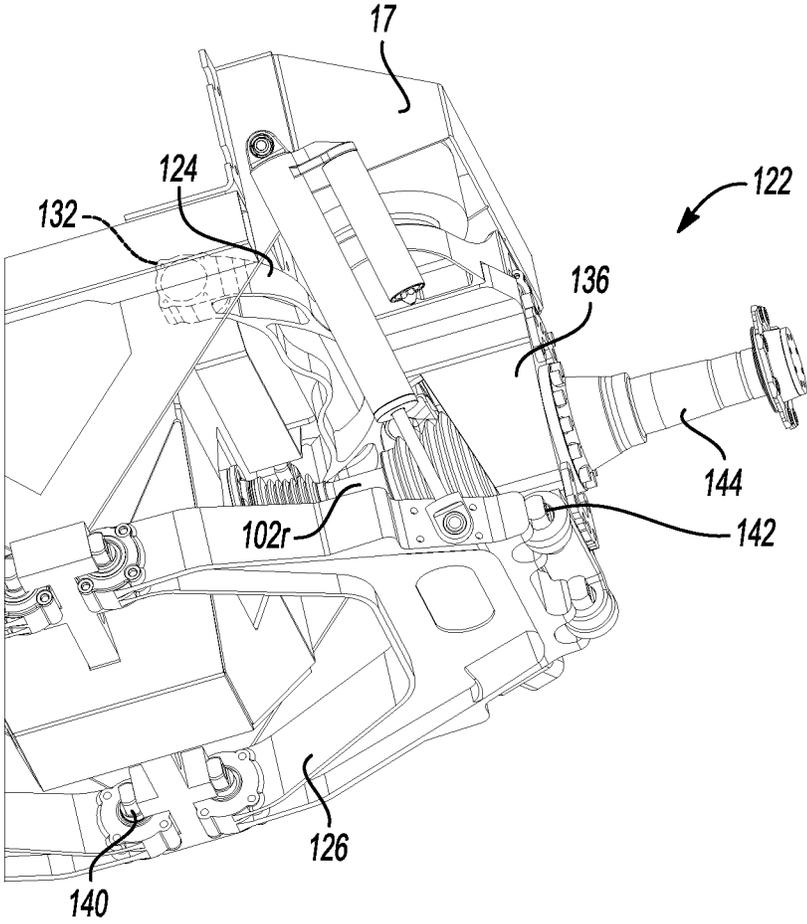


Fig-15A

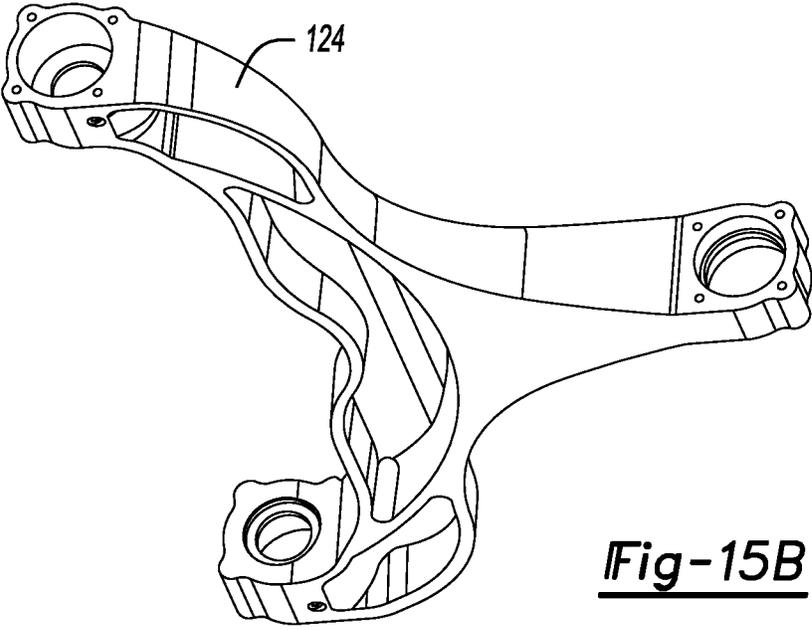


Fig-15B

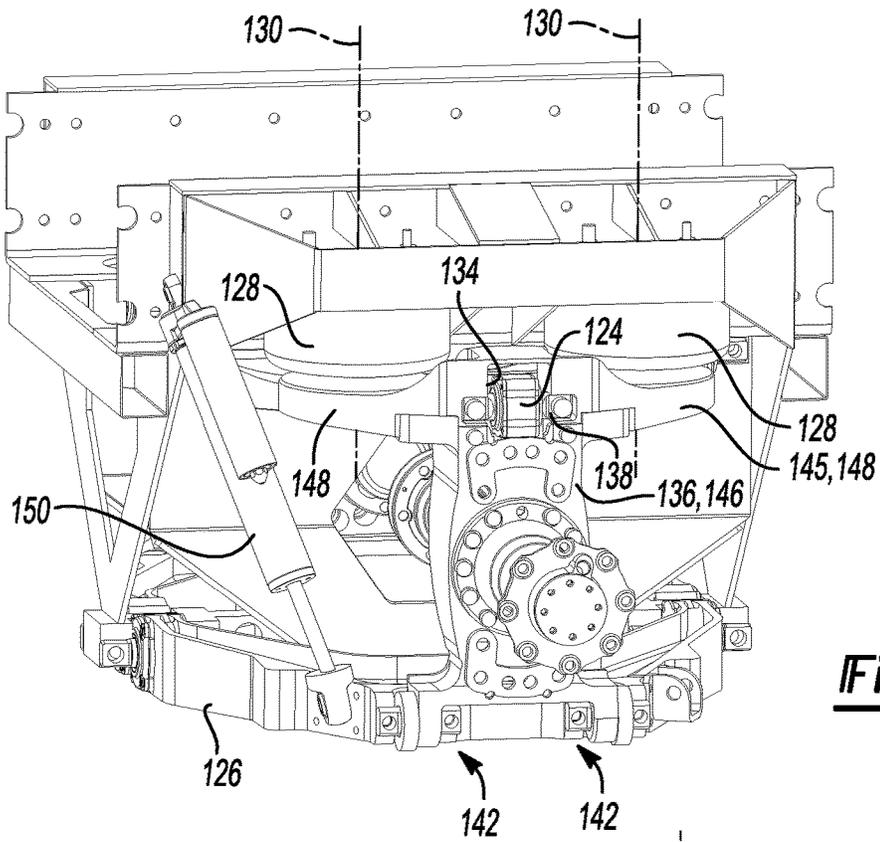


Fig-16

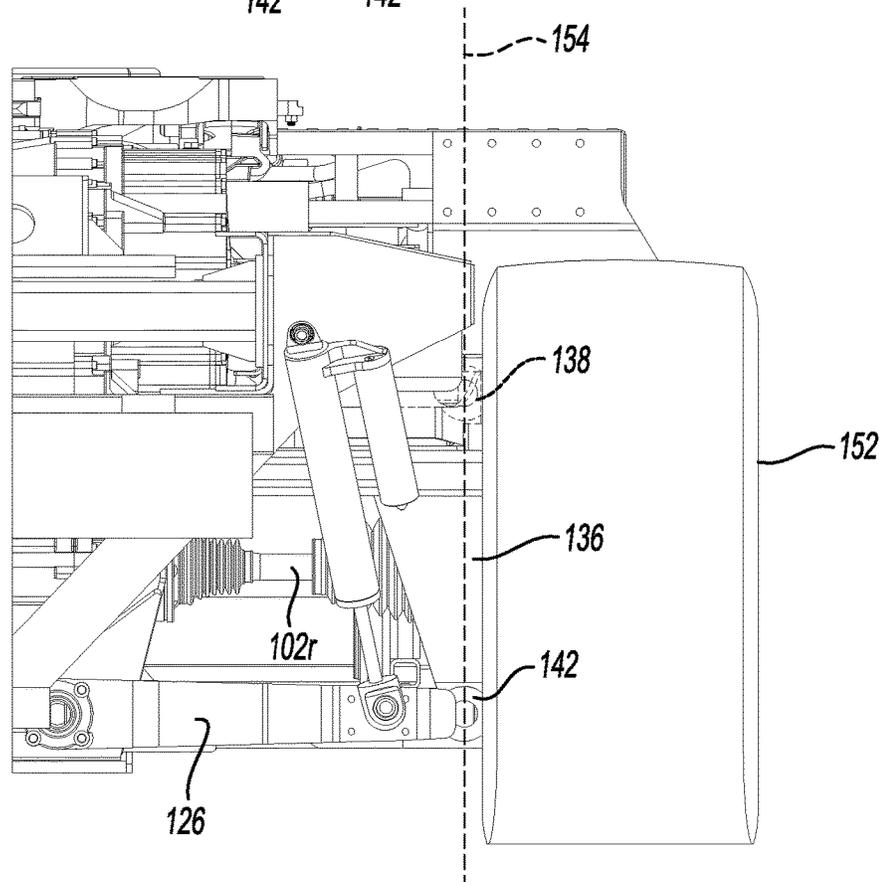


Fig-17

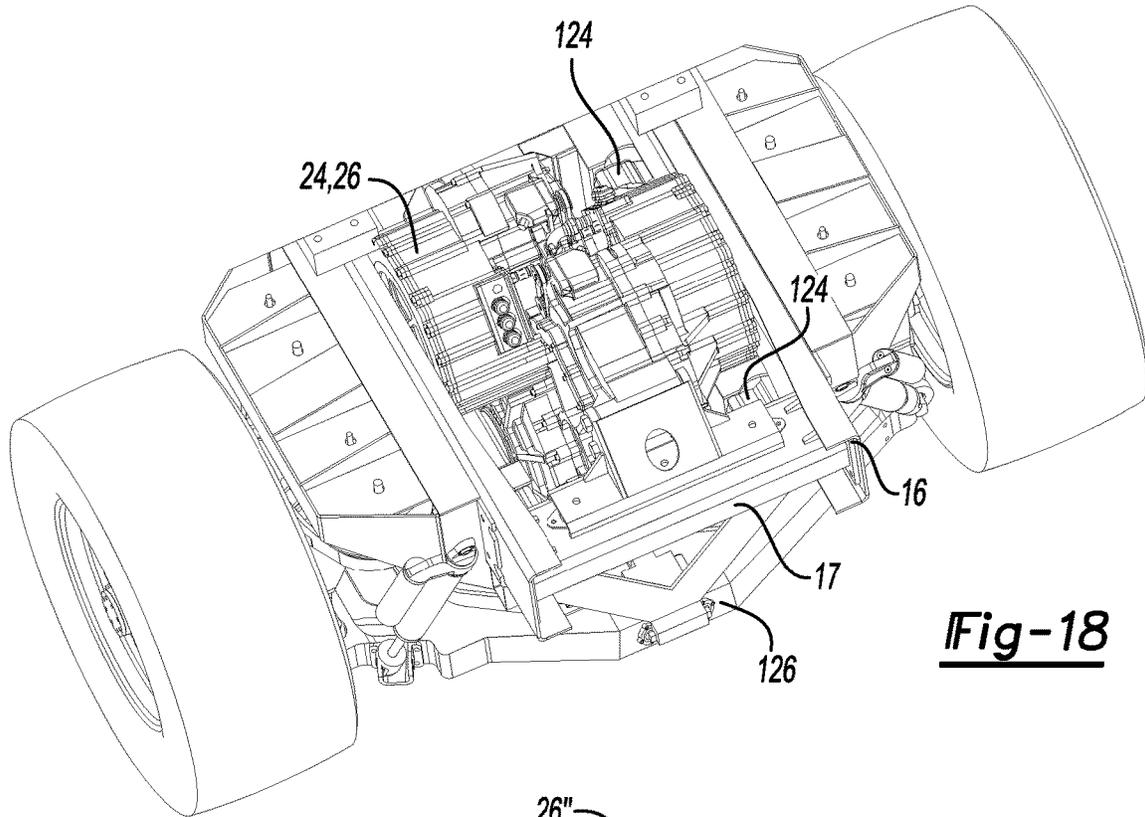


Fig-18

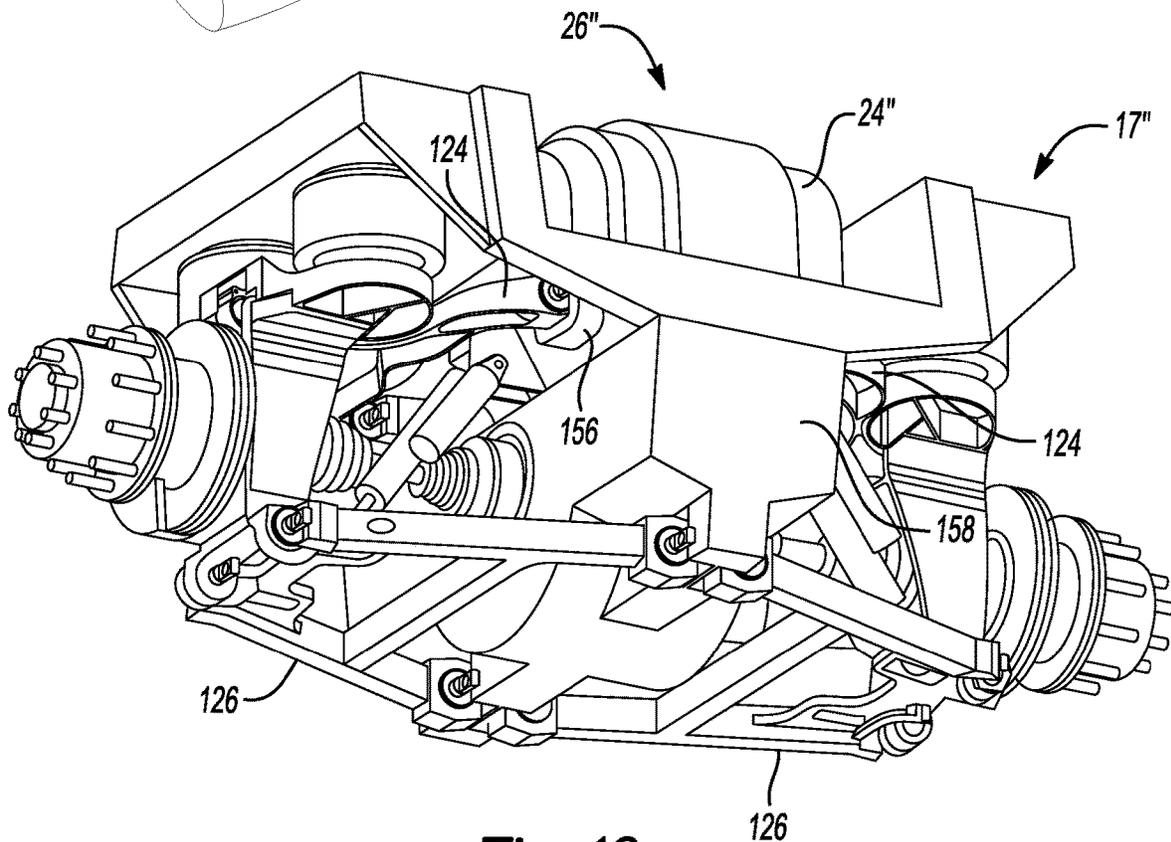


Fig-19

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MOTOR GEARBOX ASSEMBLY**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is a continuation of U.S. application Ser. No. 15/357,350 filed Nov. 21, 2016, which, in turn, claims the benefit of U.S. provisional application Ser. No. 62/391,745 filed May 9, 2016, the disclosures of which are hereby incorporated in their entireties by reference herein.

TECHNICAL FIELD

The disclosure relates to a motor gearbox assembly for use with a vehicle.

BACKGROUND

Prior vehicle drive systems are disclosed in U.S. Pat. No. 8,678,118 and U.S. Patent Application Publication No. 2010/0025131.

SUMMARY

According to one aspect of the disclosure, a motor gearbox assembly is provided for a vehicle having two wheels on opposite sides of the vehicle. The assembly includes two independent drive systems that each include an electric motor and an associated gear train, and each drive system is configured to independently drive one of the wheels. The assembly further includes a common housing that receives the motors and the gear trains such that the gear trains are at least partially positioned between the motors. At least a portion of one drive system has a generally inverse orientation with respect to at least a portion of the other drive system in a longitudinal direction of the vehicle when the motor gearbox assembly is mounted on the vehicle.

According to another aspect of the disclosure, a motor gearbox assembly for a vehicle having two wheels on opposite sides of the vehicle includes two independent drive systems that each include an electric motor and an associated gear train, and each drive system is configured to independently drive one of the wheels. The assembly further includes a common housing that receives the motors and the gear trains such that the gear trains are positioned at least partially between the motors and such that the gear trains at least partially overlap each other in a lateral direction of the vehicle when the motor gearbox assembly is mounted on the vehicle.

According to yet another aspect of the disclosure, a motor gearbox and suspension arrangement for a vehicle includes a drive system for driving a wheel of the vehicle, and the drive system includes an electric motor and a gear train associated with the motor. The arrangement further includes a housing that receives the motor and the gear train, and a suspension control arm having a first end configured to be connected to the vehicle and a second end configured to be connected to the housing.

While exemplary embodiments are illustrated and disclosed, such disclosure should not be construed to limit the claims. It is anticipated that various modifications and alternative designs may be made without departing from the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a vehicle according to the present disclosure;

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FIG. 2 is a top view of a chassis assembly of the vehicle, which includes three axle pairs connected to six wheels and three dual motor gearbox assemblies according to the disclosure for driving the wheels, wherein each wheel may be a single wheel, such as at a front of the vehicle, or a double wheel pair, such as at a rear of the vehicle;

FIG. 3 is a bottom view of the chassis assembly showing front and rear suspension systems according to the disclosure;

FIG. 4 is a perspective view of one of the motor gearbox assemblies, which includes an external housing;

FIG. 5 is a perspective view of the motor gearbox assembly of FIG. 4, with the housing removed to show first and second independent drive systems, wherein each drive system includes an electric motor and an associated gear train connected to the motor;

FIG. 6 is a perspective sectional view of the housing showing details of a lubrication passage arrangement formed in the housing;

FIG. 7 is a fragmentary perspective view of the housing showing further details of the lubrication passage arrangement;

FIG. 8 is a fragmentary side perspective view of the housing showing further details of the lubrication passage arrangement;

FIG. 9 is a top view of the first and second drive systems of FIG. 5;

FIG. 10 is a perspective view of the first drive system of FIG. 9 operating in a low gear ratio mode;

FIG. 11 is a perspective view of the first drive system of FIG. 9 operating in a high gear ratio mode;

FIG. 12 is a front perspective view of a front portion of the vehicle showing a front suspension system according to the present disclosure;

FIG. 13A is a side perspective view of the front portion of the vehicle showing additional details of the front suspension system;

FIG. 13B is a fragmentary side view of the front portion of the vehicle showing an air spring damper assembly and yoke mount of the front suspension system aligned with a front drive shaft;

FIG. 14 is a front perspective view of an alternate embodiment of the front suspension system, showing various components of the front suspension system connected to a motor gearbox housing;

FIG. 15A is a bottom perspective view of a rear portion of the vehicle showing a rear suspension system according to the present disclosure;

FIG. 15B is a perspective view of an upper suspension control arm of the rear suspension system shown in FIG. 15A;

FIG. 16 is a side perspective view of the rear portion of the vehicle showing additional details of the rear suspension system;

FIG. 17 is a rear end view of the vehicle showing a knuckle of the rear suspension system and upper and lower suspension control arms connected to the knuckle proximate a right rear tire;

FIG. 18 is a top perspective view of a rear end of the vehicle showing further details of the rear suspension system and a dual motor gearbox assembly positioned between two rear wheels and associated tires; and

FIG. 19 is a bottom perspective view of an alternate embodiment of the rear suspension system, showing various components of the rear suspension system connected to a motor gearbox housing.

DETAILED DESCRIPTION

As required, detailed embodiments are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary and that various and alternative forms may be employed. The figures are not necessarily to scale; some features may be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art.

A vehicle according to the present disclosure may be any suitable vehicle, such as a passenger car, truck, etc. FIG. 1 shows an exemplary vehicle, which is an electric driven class 8 semi-truck 10 called the NIKOLA ONE™. In one embodiment, the truck 10 may be configured to pull a total gross weight of 80,000 lbs. approximately 1,200 miles between stops, or even more than 1,200 miles between stops. The truck 10 shown in FIG. 1 has an aerodynamic cab 12, six rotatable wheels 14, and an electric motor and associated gear train (e.g., gear train with dual gear reduction) at every wheel (6×6), which motors and gear trains may be grouped in pairs to form a motor gearbox assembly as described below in further detail. In the embodiment shown in FIG. 1, the four rear wheels 14 each include a dual wheel pair (two wheels that rotate together). In the embodiment shown in FIGS. 2 and 3, the rear wheels 14 each include a relatively larger wheel and associated tire (e.g., super single wheel and tire). While each electric motor may be configured to produce any suitable horsepower (HP), such as 100 to 400 HP, in one embodiment each motor may be sized to produce 335 HP such that the truck 10, with six motors combined, may output about 2,000 HP and over 3,700 ft. lbs. of torque before gear reduction, and nearly 86,000 ft. lbs. of instant torque after gear reduction. The truck's six electric motors may produce superior horsepower, torque, acceleration, pulling and stopping power over other class 8 trucks currently on the road. The truck 10 may further include an independent suspension system, such as a short/long arm (SLA) suspension system, for each of the six wheels 14 as described below in further detail.

Referring to FIGS. 2 and 3, most of the truck's heavy components may be arranged to sit at or below a frame rail of frame 16 of chassis or vehicle support structure 17, thereby lowering the center of gravity by several feet and improving anti-roll over capabilities. This may also be partially accomplished by removing the diesel engine and transmission associated with a typical class 8 truck, and manufacturing the cab 12 out of lighter, but stronger carbon fiber panels, for example. Benefits of removing the diesel engine may include a drastic reduction in greenhouse gas emissions, a larger and more aerodynamic cab and a significantly quieter ride. Furthermore, all an operator or driver may need to use to make the truck 10 go and stop may be an accelerator or electric pedal and brake pedal (no shifting or clutches). The truck's simplified operation may open up the long haul market to a whole new group of drivers.

The truck's electric motors may be powered by any suitable energy storage system (ESS) 18, such as a rechargeable battery pack that may be charged in any suitable manner. For example, the ESS 18 may include a liquid cooled 320 kWh, lithium-ion battery pack (over 30,000 lithium cells), which may be charged by an onboard turbine of a turbine assembly 20. The turbine may automatically charge the batteries of the ESS 18 when needed and eliminate the need to ever "plug-in." The turbine may produce nearly 400 kW of clean energy, for example, which may

provide ample battery power to allow the truck 10 to climb a 6% grade at maximum weight at 65 MPH. When going downhill, the truck's six electric motors may be configured to absorb the braking energy normally lost and deliver it back to the batteries, thereby increasing component life, miles per gallon, safety, and freight efficiencies while eliminating noisy engine brakes and reducing the potential for runaway trucks.

When compared to a typical class 8 diesel truck, the turbine of the truck 10 may be much cleaner and more efficient. The turbine may also be fuel agnostic, meaning it can run on gasoline, diesel or natural gas.

Because the above configuration includes an electric motor at each wheel 14, the truck's control unit (described in further detail below) may provide dynamic control to each wheel 14. This may be referred to as "torque vectoring" and it is accomplished by controlling the speed and torque of each of the six wheels 14 independent of each other at any given moment. Such a 6×6 torque vectoring control system may allow for safer cornering, increased stopping power (e.g., doubled stopping power), improved traction, better tire wear and longer component life over current class 8 trucks.

The cab 12 of the truck 10 may be significantly larger than a typical cab (e.g., 30% larger), yet may be more aerodynamic and have a lower coefficient of drag than the typical cab (e.g., the co-efficient of drag may be nearly 5% lower compared to current trucks on the market). The cab 12 may also include various comfort and/or convenience features, such as a sliding mid-entry door for improved access and safety, a full size refrigerator and freezer, electric climate controlled cabin, touch screen display (e.g., 15 inch touch screen display), 4G LTE internet, over the air software updates, panoramic windshield, sunroof, two full size beds, microwave and large screen television (e.g., 42 inch television). All of these features may be powered by the ESS 18, thereby alleviating the need to idle or run a separate generator.

The truck's hardware and/or software may also be configured to provide compatibility with driverless vehicles in the future. Such technology may allow a single driver to "virtually" hitch and lead up to 5 driverless trucks 10 through a wireless vehicle network and self-driving technology. This technology could solve the driver shortage and increased freight costs facing the long haul transportation industry.

Motor Gearbox Description

Referring to FIGS. 2, 4 and 5, the electric motors mentioned above (which are identified with reference number 22 in FIG. 5) are grouped in pairs and each pair is mounted in a common motor gearbox housing 24 along with an associated gear train 25 for each motor 22 to form a dual motor gearbox assembly or dual motor gearbox 26. Each motor 22 and associated gear train 25 may be referred to as a powertrain, drive assembly, or drive system 28. With the above configuration, a single housing 24 encloses or receives two independent electric motors 22 and associated gear trains 25 that are capable of driving output wheels 14 on opposite sides of the housing 24 at independent speeds and/or directions. Furthermore, the housing 24 may be mounted on the frame 16 or other portion of the vehicle support structure 17, such as a subframe or suspension cradle that is attached to the frame 16.

The above configuration of the dual motor gearbox 26 may provide a smaller overall volume for the electric powertrains by structurally supporting the bearings, gears, electric motor rotor and stator, and shifting mechanism components in a smaller package designed to fit between

opposite wheels **14**, and associated wheel hubs on which the wheels **14** are mounted, of the truck **10** as shown in FIG. 2. The package design and independent nature of the dual motor gearbox **26** eliminates the need for a differential and allows the output of the motors **22** to be directly coupled to the drive wheels **14** via half-shaft direct drive drive-shafts. By eliminating large drive-shafts and differentials, greater mechanical efficiency may be achieved, and the truck **10** may be made lighter.

This design also permits full independent suspension at each axle without some of the weight and mechanical complexity that would be incurred when using a typical drive-shaft differential combination and adapting such a combination for independent suspension. Front and rear independent suspension systems according to the disclosure are explained below in detail under the headings "Front Independent Suspension Design" and "Rear Independent Suspension Design," respectively.

The two drive systems **28** of a particular motor gearbox **26** may be completely separate from each other with the exception of a forced fluid (e.g., oil) cooling and lubrication system and the structural nature of the housing **24**, which are shared. Referring to FIG. 4, the housing **24** may have an inlet **29** proximate a top of the housing **24** for receiving lubricant (e.g., oil), which may be distributed over components within the housing **24** and then collected at or near a bottom portion of the housing **24**. The housing **24** may have various passages and openings machined or otherwise formed therein for routing lubricant to desired locations within the housing **24**, as explained below in more detail. The lubricant may exit the housing **24** through one or more outlets **30** and then be routed through a cooling and filtration assembly **31** (shown in FIG. 3), which may include a cooling unit and filter, before being returned to the housing **24** through suitable passages or conduits.

Referring to FIGS. 6-8, additional details of an example configuration of the housing **24** for enabling or facilitating flow of lubricant are shown. Referring to FIG. 6, lubricant may flow from the inlet **29** through a main passage **32** to first and second passage arrangements **34** and **36**, respectively, that supply lubricant to first and second motor receptacles **38** and **40**, respectively, which each receive a motor **22**, and to first and second gear train receptacles **42** and **44** respectively, which each at least partially receive a gear train **25**. The first and second motor receptacles **38** and **40**, respectively, are located on first and second opposite sides, respectively, of a housing central wall **46**, and the first and second gear train receptacles **42** and **44**, respectively, may be at least partially located on opposite sides of the housing central wall **46**.

The second passage arrangement **36** will now be described in more detail, with the understanding that the first passage arrangement **34** may have the same or similar configuration, but with an inverse orientation, or partial inverse orientation, in a longitudinal direction (e.g., a rearwardly extending passage of the second passage arrangement **36** may correspond to a counterpart forwardly extending passage of the first passage arrangement **34**). The second passage arrangement **36** may include multiple channels or passages formed in housing walls, and multiple openings in the housing walls that allow the passages to provide lubricant to one or both of the motors **22** in the motor receptacles **38** and **40**, and one or both of the gear trains **25** in the gear train receptacles **42** and **44**. For example, the second passage arrangement **36** may include a lateral passage **48** that connects to a Y-shaped longitudinally extending manifold or passage **50**. The Y-shaped passage **50** feeds a downwardly

extending channel or passage **52** that communicates with the second gear train receptacle **44** through multiple openings formed in one or more housing walls. In addition, the Y-shaped passage **50** extends to another lateral passage **54**, which communicates with the second motor receptacle **40** through one or more openings **56** formed in a curved housing wall **58** that at least partially defines the second motor receptacle **40**. Referring to FIG. 7, the Y-shaped passage **50**, or another passage in communication with lateral passage **48**, may also feed a V-shaped longitudinally extending passage or manifold **60**, which communicates with the first gear train receptacle **42** located on the first side of the housing central wall **46** through one or more openings **62** formed in the housing central wall **46**, as shown in FIG. 8. Furthermore, the V-shaped manifold **60** may be covered by a plate **64** as shown in FIG. 4.

With the above configuration, each passage arrangement **34**, **36** is configured to supply lubricant on both sides of the housing central wall **46**. In addition, each passage arrangement **34**, **36** is configured to supply lubricant to one of the motors **22** and to at least a portion of each gear train **25**. Furthermore, lubricant may be moved through each passage arrangement **34**, **36** by pressure and/or gravity to lubricate and/or cool the motors **22** and associated gear trains **25**.

Returning to FIG. 5, each of the gear trains **25** may include multiple gears that are configured to mesh together to transmit torque from a respective motor **22** to a respective wheel **14**. Furthermore, each gear train **25** may be capable of running at multiple (e.g., two) speeds, and the gear trains **25** may have the components and capability to shift between gear ratios independent of each other. For example, each gear train **25** may include a suitable shift mechanism **72** that is controlled by an electronic control unit, which may be driven by or otherwise in communication with a vehicle control unit (e.g., a computer). With the above configuration, an automatic shifting event can be triggered for each wheel separately to limit power reduction during shifting, as explained below in further detail. The electronic control unit and/or the vehicle control unit may also control the motors **22** and/or other components of the motor gearbox **26**.

Each of the above mentioned control units may include suitable hardware and/or software, such as one or more processors (e.g., one or more microprocessors, microcontrollers and/or programmable digital signal processors) in communication with, or configured to communicate with, one or more storage devices or media including computer readable program instructions that are executable by the one or more processors so that the control unit may perform particular algorithms represented by the functions and/or operations described herein. Each control unit may also, or instead, include one or more application specific integrated circuits, programmable gate arrays or programmable array logic, programmable logic devices, or digital signal processors.

By packaging the motors **22** and gear trains **25** in a housing **24** that can fit between opposite wheels **14** of the truck **10**, a similar arrangement can be applied to each axle pair along the vehicle **10**. This effectively reduces the power requirement of each individual motor **22** by dividing the driving load between all of the motors. As result, several smaller motors with less mechanical losses can be used instead of a single large motor with more losses. Furthermore, when combined with independent control of these motors, unique control and performance gains are made available.

Referring to FIG. 9, additional details of the powertrains or drive systems **28** will now be described. FIG. 9 shows first

and second drive systems **28a** and **28b**, respectively, of a motor gearbox **26**, with the housing **24** removed. The first drive system **28a** includes first motor **22a** and associated first gear train **25a**, and the second drive system **28b** includes second motor **22b** and associated second gear train **25b**. Each drive system **28a**, **28b** also includes suitable inputs or connections **73a**, **73b** for receiving electrical power (e.g., from the ESS **18**) and/or control signals, and for providing the electrical power and/or control signals to the associated motor **22a**, **22b** and/or shift mechanisms **72**. In addition, the gear trains **25a** and **25b** may be positioned at least partially between the motors **22a** and **22b**. In the embodiment shown in FIG. **9**, the gear trains **25a** and **25b** are entirely disposed laterally between the motors **22a** and **22b**. Furthermore, staggered dividing line **74** approximately indicates general separation or division of the drive systems **28a** and **28b**.

As shown in FIG. **9**, at least portions of the drive systems **28a**, **28b** may have generally inverse orientations in a longitudinal direction **75** of the truck **10** and with respect to a laterally extending, central plane **76** of the motor gearbox **26**. In other words, at least a portion of one drive system **28a** or **28b** may have a generally inverse orientation with respect to at least a portion of the other drive system in the longitudinal direction **75** of the truck **10**. For example, the motors **22a** and **22b** may have generally inverse orientations with respect to each other in the longitudinal direction **75**, and/or portions or all of the gear trains **25a** and **25b** may have generally inverse orientations with respect to each other in the longitudinal direction **75** (e.g., at least a portion of one gear train **25a** may have a generally inverse orientation with respect to at least a corresponding portion of the other gear train **25b** in the longitudinal direction **75**). In the embodiment shown in FIG. **9**, the motors **22a** and **22b** are offset with respect to each other in the longitudinal direction **75** and have generally inverse orientations with respect to each other, and multiple gears of the first gear train **25a** each have a generally inverse orientation with respect to a corresponding gear of the second gear train **25b**. In that regard, in the embodiment shown in FIG. **9**, motor axis or central axis **77a** of motor **22a** (e.g., the axis about which the rotor of motor **22a** is rotatable) is located forward of central plane **76** by a distance d_1 , while motor axis or central axis **77b** of motor **22b** (e.g., the axis about which the rotor of motor **22b** is rotatable) is located rearward of central plane **76** by a distance d_z . Likewise, an intermediate gear **78a** of gear train **25a** is located forward of central plane **76**, while a corresponding intermediate gear **78b** of gear train **25b** is located rearward of central plane **76** (e.g., the central plane **76** extends between the intermediate gears **78a** and **78b**). In the illustrated embodiment, intermediate gear **78a** is rotatable about a gear axis **79a** that is located forward of the central plane **76** by a distance d_3 , and intermediate gear **78b** is rotatable about a gear axis **79b** that is located rearward of the central plane **76** by a distance d_4 . Furthermore, in the embodiment shown in FIG. **9**, distance d_1 is equal to distance d_2 , and distance d_3 is equal to distance d_4 . Output gears **80a** and **80b** of the gear trains **25a** and **25b**, however, may be aligned along the central plane **76**, and may also be axially aligned so that the corresponding wheels **14** can be axially aligned. Therefore, the output gears **80a** and **80b** may be aligned with each other, while the other corresponding components of the drive systems **28a** and **28b** may be offset with respect to each other in the longitudinal direction **75**. In some embodiments, corresponding components of the drive systems **28a** and **28b** may be offset with respect to each other, but spaced relative to the central plane **76** by different distances.

As further shown in FIG. **9**, some corresponding components of the gear trains **25a** and **25b** may be offset with respect to each other by greater distances in the longitudinal direction **75** than the motors **22a** and **22b**. For example, in the embodiment shown in FIG. **9**, the central axes **77a** and **77b** of the motors **22a** and **22b** are spaced apart by a first distance equal to the sum of d_1 and d_2 , while the gear axes **79a** and **79b** of the intermediate gears **78a** and **78b** are spaced apart by a second distance equal to the sum of d_3 and d_4 , wherein the second distance is greater than the first distance.

It should also be noted that each drive system **28a** and **28b** is configured to independently drive a wheel **14** that is located on the same side of the truck **10** as the corresponding motor **22a**, **22b** when the motor gearbox **26** is mounted on the frame **16** or other portion of the vehicle support structure **17**. Referring to FIG. **9**, the first drive system **28a** is configured to drive a wheel **14** (not shown) positioned proximate motor **22a** and to the left of motor **22a**, while the second drive system **28b** is configured to drive a wheel **14** (not shown) positioned proximate motor **22b** and to the right of motor **22b**. In that regard, output gear **80a** may be connected by a first drive shaft or drive half-shaft (not shown) to a wheel **14** located to the left of the motor **22a**, and output gear **80b** may be connected by a second drive shaft or drive half-shaft (not shown) to a wheel **14** located to the right of the motor **22b**.

As also shown in FIG. **9**, the gear trains **25a** and **25b** may at least partially overlap each other in a lateral direction **81** of the truck **10** (e.g., at least a portion of the gear train **25a** may overlap at least a portion of the gear train **25b**) so that the lateral width of the overall motor gearbox **26** may be reduced. In other words, portions of the gear trains **25a** and **25b** may occupy a shared volume **82** within the housing **24**. For example, the intermediate gears **78a** and **78b** may at least partially laterally overlap each other. In the embodiment shown in FIG. **9**, the intermediate gears **78a** and **78b** fully overlap each other so that they are aligned in the longitudinal direction **75**.

With the configuration described above, the motor gearbox **26** may have a compact design. As result, and as mentioned above, a motor gearbox **26** according to the disclosure may be positioned at each axle of the truck **10**. Motor Gearbox Control Capabilities

As mentioned above, the motor gearbox design according to the present disclosure enables each gear train **25** and associated output wheel **14** to run at multiple (e.g., two) gear ratios. The output gear ratio for each drive wheel **14** can effectively be shifted independently of all other wheels **14**. FIG. **10** shows the first drive system **28a** operating in a low gear mode or low gear ratio mode with arrows indicating direction of rotation of the rotor of the motor **22a** and gears of the gear train **25a**, and FIG. **11** shows drive system **28a** operating in a high gear mode or high gear ratio mode with arrows indicating direction of rotation of the rotor of the motor **22a** and gears of the gear train **25a**. The rotor of the motor **22a** may also be rotated in an opposite direction to that shown in FIGS. **10** and **11** to thereby cause gears of the gear train **25a** to rotate in opposite directions compared to the directions shown in FIGS. **10** and **11**. As mentioned above, the gear train **25a** may include a suitable shift mechanism **72** for shifting the gear train **25a** between the gear ratio modes. For example, the shift mechanism **72** may include a barrel cam **83** that is actuated by a rotary or linear actuator that may be located at least partially external to the motor gearbox **26** and controlled by the above-mentioned electronic control unit. The barrel cam **83** may be rotated or

otherwise moved to cause one or more shift selector forks **84** to move linearly and thereby cause one or more dog gears **85**, **86** to engage or disengage adjacent gears in order to shift the gear train **25a** between the gear ratio modes.

In the low gear ratio mode shown in FIG. **10**, the dog gear **85** is in an engaged condition and the dog gear **86** is in a disengaged condition. Furthermore, in the low gear ratio mode, rotation of the rotor of motor **22a** in a first direction causes input gear **87** to likewise rotate in the first direction, and the input gear **87** engages (e.g., meshes with) first intermediate or driven gear **88** and causes the first driven gear **88** to rotate in a second direction opposite the first direction. Because the dog gear **85** is in the engaged condition, the first driven gear **88** causes second intermediate or driven gear **89** to likewise rotate in the second direction. The second driven gear **89** engages (e.g., meshes with) third intermediate or driven gear **90** and causes the third driven gear **90** to rotate in the first direction, and the third driven gear **90** engages (e.g., meshes with) the intermediate gear **78a** (which may also be referred to as a driven gear, e.g., fourth driven gear) and causes the intermediate gear **78a** to rotate in the second direction. The intermediate gear **78a** is coupled to a fifth intermediate or driven gear **91** such that rotation of the intermediate gear **78a** in the second direction causes the fifth driven gear **91** to also rotate in the second direction. The fifth driven gear **91** engages (e.g., meshes with) the output gear **80a** and causes the output gear to rotate in the first direction.

In the high gear ratio mode shown in FIG. **11**, the dog gear **85** is in a disengaged condition and the dog gear **86** is in an engaged condition. Furthermore, in the high gear ratio mode, rotation of the rotor of motor **22a** in the first direction causes the input gear **87** to likewise rotate in the first direction. Because the dog gear **86** is in the engaged condition, the input gear **87** causes sixth intermediate or driven gear **92** to likewise rotate in the first direction. The sixth driven gear **92** engages (e.g., meshes with) the intermediate gear **78a** (e.g., fourth driven gear) and causes the intermediate gear **78a** to rotate in the second direction. The intermediate gear **78a** causes the fifth driven gear **91** to also rotate in the second direction as explained above, and the fifth driven gear **91** engages (e.g., meshes with) the output gear **80a** and causes the output gear to rotate in the first direction.

During a transmission shift on a typical vehicle, the total power of a vehicle would need to be de-coupled from the transmission/drivetrain using a clutch. This results in a momentary complete loss of power during this shifting event. With the independent shifting control afforded by the motor gearbox design of the present disclosure, vehicle shifting events can be staggered among the independent gear trains around the vehicle. For example, where there are three motor gearboxes **26** (one per axle) and six independent motors **22** (one per output wheel **14** or dual wheel pair), the staggered shifting would allow one of these six gear trains **25** to be shifted at a time and then sequentially through the other gear trains. This means that instead of a total loss of power during shifting, there would only be a 1/6th reduction in power at any given time during the shift event. As a result, there is constant power, although slightly reduced, as the truck **10** shifts. Furthermore, with the above configuration, a shifting event can be controlled to be efficient and smooth, without the driver feeling it happen.

Vehicle electronic stability control (ECS), or traction control, may also be performed by braking or reducing power to wheels **14** to prevent slipping and improve traction. With independent speed and torque control of all wheels **14**,

it is possible to provide more torque to wheels **14** that have traction and are maintaining speeds to prevent slipping of other wheels **14**. It is also possible to provide full torque vectoring during turning or high-speed avoidance. This may provide greater stability and cornering performance by distributing torque where it is needed during these maneuvers.

Independent motor **22** to wheel **14** coupling as a result of this design also allows independent regenerative braking or deceleration of the wheels **14**. This means that braking force/torque could be distributed independently to each of the wheels **14** using the wheel motors **22** as generators, which may provide power back to the battery or energy storage system (e.g., ESS **18**). Furthermore, the motor gearboxes **26** could be controlled to provide regenerative braking and deceleration at or near the friction limit of the tires of the truck **10**. This may be possible by using wheel speed and direction sensors that are embedded in each motor gearbox **26** and sense the speed and/or direction of a gear in each gear train **25** that is directly coupled to a particular wheel **14**. For example, each drive system **28a**, **28b** of a motor gearbox **26** may include a primary gear speed and direction sensor **93** positioned proximate the associated intermediate gear **78a**, **78b** (e.g., proximate an outer circumference of the intermediate gear and oriented generally transverse to the associated axis), as well as a secondary gear speed sensor **94** that may be positioned on a side of the associated intermediate gear **78a**, **78b**.

Front Independent Suspension Design

Referring to FIGS. **2**, **3** and **12-13B**, the truck **10** further includes front independent suspension systems **95** designed around the front motor gearbox **26** and drive half-shafts intended to drive the front wheels **14** of the vehicle **10**. Typical Class **8** trucks do not have front wheel drive, so a unique design was developed to allow driving, steering and independent suspension. Furthermore, the front suspension systems **95** may be designed to accommodate an air brake system (e.g., air disc brake system) that is used for braking the front wheels **14**. The front suspension system **95** for one of the front wheels **14** is shown in FIGS. **12-13B**, with the understanding that the truck **10** may include the same or similar front suspension at the other front wheel **14**.

Referring to FIG. **12**, adding front wheel drive capability adds complexity due to the number of moving components vying for the same space near the front wheel **14**. Such components may include air brake system components (e.g., an air brake chamber **96** and brake caliper assembly **97** that is actuated by the air brake chamber **96**), a steering arm or link **98** of a steering system for steering the front wheel, front suspension system components (e.g., upper and lower independent suspension control arms **99** and **100**, respectively) and a drive half-shaft **102** and corresponding constant velocity (CV) joint, for example. To allow those components to connect to or otherwise be associated with the front wheel **14**, a custom front support member or knuckle **104** was developed for the front suspension system **95**. The knuckle **104** rotatably supports the front wheel **14** and associated hub, and may serve as a direct or indirect connection or support area for various components (e.g., the knuckle **104** may be configured to support various components). For example, the steering arm **98** may be pivotally connected to the knuckle **104** in any suitable manner, such as with a knuckle mount that includes a pivot member (e.g., pivot ball) and a pivot bearing (e.g., pivot socket). Likewise, the control arms **99** and **100** of the front suspension system **95** may each be pivotally connected to the knuckle **104** in any suitable manner, such as with knuckle mounts that each include a pivot member (e.g., pivot ball) and a pivot bearing

(e.g., pivot socket). As another example, the air brake chamber 96 may be mounted on the knuckle 104 or on the brake caliper assembly 97, which may be mounted on the knuckle 104. Furthermore, referring to FIGS. 13A and 13B, the air brake chamber 96 may be mounted rearward of a center (e.g., rotation axis 105) of the front wheel 14 and associated hub, and proximate or outwardly of an outer circumference of the front wheel 14, to avoid contact with the drive half-shaft 102 and CV boot 106 (which covers the CV joint), steering arm 98, and suspension control arms 99 and 100 during all steering and suspension operational situations (e.g., through full suspension travel and full steering travel of the front wheel 14).

Referring to FIG. 13B, the air brake chamber 96 may also be mounted above the rotation axis 105 of the front wheel 14 and associated hub. Likewise, the air brake chamber 96 may be mounted rearward of a vertical plane 107 that passes through the rotation axis 105 and a top portion of the front wheel 14, such that the air brake chamber 96 is mounted rearward of a top-center of the front wheel 14. For example, the air brake chamber 96 may be mounted rearward of the vertical plane 107 such that a center point of the air brake chamber 96 is positioned at an angle in the range 10° to 90° (more particularly 30° to 75°) relative to the vertical plane 107 and axis 105.

Referring to FIGS. 12-13B, the front suspension system 95 further includes a unique support member or yoke mount 108 for attaching a suspension device, such as a gas (e.g., air) spring and damper assembly 109, to the lower control arm 100. The spring and damper assembly or spring-damper assembly 109 may include a gas spring 110 (e.g., air spring) and a damper 112 axially aligned with and positioned beneath the gas spring 110. The yoke mount 108 includes first and second legs 113 and 114, respectively, that are configured to receive the drive half-shaft 102 therebetween so that the spring-damper assembly 109 may be positioned over the drive half-shaft 102 (e.g., axis of the drive half-shaft 102). With such a configuration, the drive half-shaft 102 (e.g., axis of the drive half-shaft 102) may be aligned with a yoke mount axis and spring-damper assembly axis in order to keep the drive half-shaft 102 and spring-damper assembly 109 in their ideal alignment, as shown in FIG. 13B. One of the legs (e.g., first leg 113) of the yoke mount 108 may also be configured to extend between the drive half-shaft 102 and the steering arm 98. While the yoke mount 108 may be connected to the spring-damper assembly 109 in any suitable manner, in the embodiment shown in FIGS. 13A and 13B, the first and second legs 113 and 114 are fixedly connected to the spring-damper assembly 109 at first and second spaced apart locations, respectively. Furthermore, the spring 110 may be connected to the frame 16 or other portion of the vehicle support structure 17 (e.g., subframe or suspension cradle).

Alternatively, the above-mentioned suspension device may be any suitable suspension device, such as a linear or non-linear dynamic suspension member. For example, the suspension device may include a coil spring, a magnetic suspension member and/or an electromagnetic suspension member.

The front suspension systems 95 are also configured to fit around the front motor gearbox 26, which is centered within the suspension cradle. This makes it possible to have independent front suspensions while also being able to directly drive left and right front wheels 14 independently using the electric dual motor gearbox 26 located in between the front wheels 14. In the embodiment shown in FIG. 13A, inboard ends of the control arms 99, 100 may be pivotally connected

to the vehicle support structure 17 (e.g., suspension cradle or frame 16) proximate the motor gearbox 26 and the center of the truck 10.

In another embodiment, the housing 24 of the front motor gearbox 26 may be connected to at least one of the control arms 99 and 100 of one or both of the front suspension systems 95. In the embodiment shown in FIG. 14, for example, front motor gearbox 26' includes an enlarged housing 24' to which the control arms 99 and 100 of right and left front suspension systems 95 are connected. In the illustrated embodiment, each of the right and left sides of an upper portion of the housing 24' has two upper, laterally projecting portions 116 to which a particular upper control arm 99 is pivotally connected. Furthermore, the housing 24' includes an enlarged lower portion 118, and each of the right and left sides of the lower portion 118 has two lower, laterally projecting portions 120 to which a particular lower control arm 100 is pivotally connected. The housing 24' may be connected to vehicle support structure 17' (e.g., front suspension cradle or frame 16) and may be made of a suitable material, such as metal (e.g., aluminum), carbon-reinforced plastic or other composite material, etc., so that the housing 24' may support the above components. With such a configuration, portions of the front suspension cradle may be omitted, so that the overall vehicle weight may be reduced. In addition, the front suspension cradle may be integrally formed with the housing 24' (e.g., molded together), as shown in FIG. 14, to further reduce vehicle weight, or the suspension cradle may be formed separately from the housing 24' and attached to the housing 24'.

Rear Independent Suspension Design

Referring to FIGS. 3 and 15A-18, the truck 10 further includes rear independent suspension systems 122 and associated cradles that are configured to provide independent suspension at each rear wheel 14, while also allowing direct independent driving of the rear wheels 14 using a dual motor gearbox 26 located between the wheels 14 at each of two rear axle locations. The rear suspension systems 122 may also be configured to enable accurate alignment (e.g., coaxial alignment) of drive half-shafts 102r connected to each rear motor gearbox 26, so that the output gears 80 of each rear motor gearbox 26 may be coaxially aligned with corresponding rear wheels 14 when the drive half-shafts 102r are positioned in a horizontal orientation. With such a configuration, the rear suspension systems 122 may provide improved suspension travel and feel. The rear suspension system 122 for one of the rear wheels 14 is shown in FIGS. 15A-16, with the understanding that the truck 10 may include the same or similar rear suspension at each rear wheel 14.

Referring to FIGS. 15A-16, the rear suspension system 122 includes upper and lower control arms 124 and 126, respectively, that may be configured to have inboard pivot points or axes located as close to the center of the truck 10 as possible (around an associated motor gearbox 26) to allow the most accurate suspension travel from full jounce to rebound (i.e., full up and down movement). Likewise, as explained below in detail, the control arms 124 and 126 may also be configured to have outboard pivot points or axes as close to an associated rear tire as possible. In addition, the rear suspension system 122 may include one or more suspension devices, such as gas suspension members or air springs 128 that are each oriented along an upright axis 130 (e.g., central axis) and connected to the vehicle support structure 17 (e.g., suspension cradle or frame 16). Alternatively, each suspension device may comprise any suitable suspension device, such as a linear or non-linear dynamic

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suspension member. For example, each suspension device may comprise a coil spring, a magnetic suspension member and/or an electromagnetic suspension member.

In the embodiment shown in FIGS. 15A-16, the upper control arm 124 includes a first or inboard portion having two arms, and a second or outboard portion formed as a single arm. Inboard ends of the upper control arm 124 are each pivotally attached to the vehicle support structure 17 (e.g., suspension cradle or frame 16), such as with a cradle mount 132 (e.g., pivot member or rod and pivot bearing), at a location around the exterior of the motor gearbox 26 and proximate the center of the truck 10. The outboard portion of the upper control arm 124 may pass between two air springs 128 and/or between the associated upright axes 130 of the air springs 128. In the embodiment shown in FIG. 16, the outboard portion of the upper control arm 124 is centered between the upright axes 130 of the air springs 128. In addition, the outboard portion of the upper control arm 124 extends into an opening 134 in a rear support member or knuckle 136, to which the two air springs 128 are mounted. The outboard portion further includes a single wheel side end or outboard end that may be pivotally connected to the knuckle 136, such as with a knuckle mount 138 (e.g., pivot member or rod and pivot bearing), at a location proximate an outboard side of the knuckle 136 (e.g., as close to a corresponding rear wheel as possible). For example, the outboard end of the upper control arm 124 may be pivotally connected to an outboard face of the knuckle 136. As a more detailed example, the outboard end of the upper control arm 124 may be pivotally connected to the knuckle 136 with a knuckle mount 138 including a pivot member, such as a pivot rod, that is fixedly received in a channel or notch formed in the outboard face of the knuckle 136 and about which the upper control arm 124 is pivotable.

The lower control arm 126 includes an inboard portion having two inboard ends that are each pivotally attached to the vehicle support structure 17 (e.g., suspension cradle or frame 16), such as with a cradle mount 140 (e.g., pivot member or rod and pivot bearing), at a location beneath the motor gearbox 26. In the embodiment shown in FIG. 15A, the cradle mounts 140 of the lower control arm 126 are located closer to the center of the truck 10 than the cradle mounts 132 of the upper control arm 124. Such a configuration may provide improved suspension response, while also providing improved suspension travel. In addition, the lower control arm 126 includes an outboard portion that may have two wheel side or outboard side connection locations that are each supported by and pivotally attached to the knuckle 136 (e.g., at a lower end of the knuckle 136), such as with a knuckle mount 142 (e.g., pivot member or rod and pivot bearing).

Referring to FIG. 15A, the knuckle 136 is also configured to rotatably support a rear wheel 14 (e.g., dual wheel pair). For example, the knuckle 136 may be attached to a wheel spindle 144 that supports a rear wheel 14 (e.g., the wheel spindle 144 may be attached to a hub on which the rear wheel 14 is mounted).

In the embodiment shown in FIG. 16, the knuckle 136 includes upper and lower portions 145 and 146, respectively. Furthermore, the knuckle 136 may be made as a single piece or multiple pieces that are joined together, such as by welding. The upper portion 145 of the knuckle 136 may include support sections 148 that project outwardly with respect to the lower portion 146, and the opening 134 formed in the knuckle 136 may extend through a central portion of the upper portion 145 and between the support sections 148. The configuration of the knuckle 136 enables

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two air springs 128, or other suspension devices, to be mounted to a top of the knuckle (e.g., the upper portion 145) and further allows the second portion of the upper control arm 124 to pass through a majority or all of the knuckle 136 to the outside or outboard face of the knuckle 136. In addition, the second portion of the upper control arm 124 may be aligned with a central vertical axis of the knuckle 136 and an axis of the wheel 14 and associated hub.

The rear suspension system 122 may further include one or more shock absorbers or dampers 150 connected between the lower control arm 126 and the vehicle support structure 17, such as the suspension cradle or frame 16. In the embodiment shown in FIG. 16, the damper 150 is positioned rearward of the air springs 128 and knuckle 136.

With the above configuration, the rear suspension system 122 may handle significant loads, while maintaining a low profile. For example, the air springs 128 may cooperate to effectively handle large loads, yet each air spring 128 may be sized to fit between the frame rail of the frame 16 and an associated rear tire. Furthermore, the upper control arm 124 and knuckle 136 may cooperate to keep loads centered on the associated rear drive half-shaft 102:

Referring to FIG. 17, outboard portions or ends of the upper and lower control arms 124 and 126, respectively, may be pivotally connected to the knuckle 136 proximate rear tire 152 and associated wheel 14. For example, the outboard ends of the control arms 124 and 126 may be pivotally connected to the knuckle 136 as close to the tire 152 as possible (e.g., within 15 cm of an inboard face of the tire 152, or 10 cm or less of the inboard face of the tire 152). Furthermore, connection locations (e.g., pivot point or pivot axis locations) of the outboard portions of the control arms 124 and 126 with the knuckle 136 may be generally vertically aligned with each other, when viewed in the longitudinal direction 75 of the truck 10. In other words, connection locations of the outboard portions of the control arms 124 and 126 with the knuckle 136 may fall generally within a vertical plane 154 that is oriented in the longitudinal direction 75 of the truck 10. For example, the outboard side mount 138 of the upper control arm 124 may be vertically aligned with the outboard side mounts 142 of the lower control arm 126, when viewed in the longitudinal direction 75, such that the outboard side mount 138 of the upper control arm 124 and the outboard side mounts 142 of the lower control arm 126 are located in the vertical plane 154. With the above configuration of the knuckle 136 and corresponding connections to the control arms 124 and 126, the tire 152 and associated wheel 14 may be able to maintain close to a vertical orientation with respect to a road surface through the full travel range of the rear suspension system 122. As a result, the rear suspension system 122 may provide improved tracking of the tire 152.

FIG. 18 shows the inboard portions or ends of the upper and lower control arms 124 and 126, respectively, pivotally connected to the vehicle support structure 17 (e.g., suspension cradle or frame 16) proximate the center of the truck 10 and motor gearbox 26. In another embodiment, inboard portions or ends of one or both of the control arms 124 and 126 of each rear suspension system 122 for a particular rear axle may be pivotally connected to the housing 24 of the associated motor gearbox 26. In the embodiment shown in FIG. 19, for example, motor gearbox 26" includes an enlarged housing 24" to which the control arms 124 and 126 of aligned rear suspension systems 122 are connected. In the illustrated embodiment, each of the right and left sides of an upper portion of the housing 24" has two upper, laterally projecting portions 156 to which a particular upper control

arm 124 is pivotally connected. Furthermore, the housing 24" includes an elongated lower portion 158 to which the lower control arms 126 are pivotally connected. The housing 24" may be connected to vehicle support structure 17" (e.g., suspension cradle or frame 16) and may be made of a suitable material, such as metal (e.g., aluminum), carbon-reinforced plastic or other composite material, etc., so that the housing 24" may support the above components. With such a configuration, portions of the suspension cradle may be omitted, so that the overall vehicle weight may be reduced. In addition, the suspension cradle may be integrally formed with the housing 24" (e.g., molded together) to further reduce vehicle weight, or the suspension cradle may be formed separately from the housing 24" and attached to the housing 24".

While exemplary embodiments are described above, it is not intended that these embodiments describe all possible forms according to the disclosure. The words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the disclosure. Additionally, the features of various implementing embodiments may be combined to form further embodiments according to the disclosure.

What is claimed is:

1. A motor gearbox and suspension arrangement for a vehicle having a knuckle that supports a wheel, the arrangement comprising:

- a drive system for driving the wheel of the vehicle, the drive system including an electric motor and a gear train associated with the motor;
- an additional drive system for driving an additional wheel of the vehicle, the additional drive system including an additional electric motor and an additional gear train associated with the additional electric motor;
- a housing that receives and encloses the motor, the gear train, the additional electric motor, and the additional gear train; and
- a suspension control arm having a first end configured to be connected to the knuckle of the vehicle and a second end configured to be pivotally connected directly to the housing;

wherein at least a portion of the drive system has a generally inverse orientation with respect to at least a portion of the additional drive system in a longitudinal direction of the vehicle when the arrangement is mounted on the vehicle, so that the at least a portion of the drive system and the at least a portion of the additional drive system are offset with respect to each other in the longitudinal direction when the arrangement is mounted on the vehicle.

2. The arrangement of claim 1 wherein the gear train and the additional gear train at least partially overlap each other in a lateral direction of the vehicle when the arrangement is mounted on the vehicle.

3. The arrangement of claim 2 wherein the gear train and the additional gear train each include an intermediate gear, and the intermediate gears have generally inverse orientations with respect to each other in the longitudinal direction when the arrangement is mounted on the vehicle.

4. The arrangement of claim 3 wherein the gear train and the additional gear train each have an output gear, and the output gears are axially aligned with each other.

5. The arrangement of claim 4 wherein the motor and the additional motor are offset with respect to each other in the longitudinal direction of the vehicle when the arrangement is mounted on the vehicle.

6. The arrangement of claim 2 wherein the motor and the additional motor are offset with respect to each other in a longitudinal direction of the vehicle when the arrangement is mounted on the vehicle.

7. The arrangement of claim 6 wherein the gear train and the additional gear train each include an output gear, and the output gears are axially aligned with each other.

8. The arrangement of claim 2 wherein the motor and the additional motor have generally inverse orientations with respect to a laterally extending central plane when the arrangement is mounted on the vehicle.

9. The arrangement of claim 8 wherein the motor is aligned about a central axis, and the additional motor is aligned about an additional central axis, and wherein the central axis of the motor is located forward of the central plane by a first distance when the arrangement is mounted on the vehicle, and the additional central axis of the additional motor is located rearward of the central plane by a second distance when the arrangement is mounted on the vehicle, and wherein the first and second distances are the same.

10. The arrangement of claim 8 wherein the gear train and the additional gear train each include an intermediate gear, and the central plane extends between the intermediate gears when the arrangement is mounted on the vehicle.

11. The arrangement of claim 2 wherein the gear train and the additional gear train each include an intermediate gear, and the intermediate gears at least partially laterally overlap each other when the arrangement is mounted on the vehicle.

12. A vehicle comprising:

- a wheel;
 - a knuckle that supports the wheel;
 - a drive system for driving the wheel, the drive system including an electric motor and a gear train associated with the motor;
 - an additional wheel and an additional drive system for driving the additional wheel, the additional drive system including an additional electric motor and an additional gear train associated with the additional electric motor;
 - a housing that receives and encloses the motor, the gear train, the additional electric motor, and the additional gear train; and
 - a suspension control arm having a first end connected to the knuckle and a second end pivotally connected directly to the housing;
- wherein the gear train and the additional gear train at least partially overlap each other in a lateral direction of the vehicle.

13. The vehicle of claim 12 wherein at least a portion of the drive system has a generally inverse orientation with respect to at least a portion of the additional drive system in a longitudinal direction of the vehicle, so that the at least a portion of the drive system and the at least a portion of the additional drive system are offset with respect to each other in the longitudinal direction.

14. The vehicle of claim 12 further comprising a drive shaft connected to the wheel, and wherein the drive system is operable to drive the drive shaft.

15. The vehicle of claim 12 wherein the second end of the suspension control arm is disposed inwardly of the first end.